GRAVITY SURVEY OF THE MT. TOONDINA IMPACT STRUCTURE SOUTH AUSTRALIA

J. B. Plescia[1], E. M. Shoe.make.r[2], and C. S. Shoemaker[2]

[1] Jet Propulsion Laboratory
Earth and Space Sciences Division
California Institute of Technology
Pasadena, CA 91 109

[2] U. S. Geological Survey
Branch of Astrogeology
Flagstaff, AZ 86001

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ABSTRACT

Gravity and seismic reflection data, together with geologic mapping, indicate that the Mount Toondina feature in South Australia is an eroded 4-km-diameter impact structure consisting of a ring structural depression surrounding a pronounced central uplift. Beds in the central uplift have been raise.d as much as 200 m from depth and deformed by convergent flow. Seismic reflection data indicate that this deformation extends to depths of only ~800 m; at greater depths the reflectors are. nearly flat lying indicating little. or no deformation below this depth. Gravity data, after removal of regional effects by polynomial approximation, indicate that the structure is characterized by a residual gravity anomaly of +1.() mGal coincident with the central uplift and a -0.S regal annular low associated with the ring structural depression. Gravity modeling indicates that relatively high-density material has been structurally uplifted; the ring depression surrounding the central uplift is filled with low density strata which are thicker by as much a s 90 m relative to their thickness outside the structure. The deformation at Mt. Toondina is typical of a collapsed impact crater of mode.rate. size and the 4-km diameter is consistent with the expected threshold size for collapse of craters formed in weak to moderate strength sedimentary rocks.

INTRODUCTION

The Mt. Toondina impact structure [*Shoemaker and* Shoemaker, 1990] is located in northern South Australia, -45 km south of the town of Oodnadatta and is centered at 27° 57' S, 135° 22' E (Figure 1). The strut.ture (Figure 2) is characterized by a central uplift of intensely folded and faulted rocks surrounded by a ring structural depression. The entire Mt. Toondina impact structure has a diameter of about four kilometers and an age of less than 110 Ma. The original crater has been eroded away and the minor topographic promontory of "Mt. Toondina" is formed by a series of travertine spring deposits of Pleistocene or possibly late Tertiary age capping the uplifted and contorted rocks of the central uplift. The ring structural depression surrounding the central uplift is concealed belle.a(ll a thin veneer of Quaternary surficial deposits.

in an attempt to better define the diameter and structure of the impact feature, detailed geologic mapping and a gravity survey were carried out. Here, we present the results of the gravity survey and the impli cations of the gravity and seismic reflection data for the origin of the Mt. Toondina structure.

GEOLOGIC BACKGROUND

The Mt. Toondina structure was originally recognized as a structural anomaly from exposures of folded and faulted Permian, Jurassic, and Cretaceous rocks surrounded by a broad expanse of nearly flat-lying beds of the. Bulldog Shale of Early Cretaceous age. The feature occurs in the Arckaringa Sub-basin of the Great Artesian Basin of east-central Australia. The Mt. Toondina structure was first mapped by *Freytag* [1 964, 1965] who discovered and described the Lower Permian Mt. Toondina Beds and prepared a sketch map of the. exposed rocks of the central uplift. He also recognized exposure.s of the Alge buckina Sandstone of Jurassic (?) age and fine sandstone and shale. now assigne d to the Cadna-owie Formation of Early Cretaceous age.

that are locally exposed on the flanks of the central uplift. The Algebuckina Sandstone. is a regional aquifer; numerous springs issue from the. exposed sandstone, and travertine spring deposits cap and conceal many parts of the uplift (Figure 2).

Freytag [1964, 1965] interpreted the structure and the displacement of beds in the central uplift largely in terms of a network of faults. Unpublished, detailed geologic mapping by E. M. Shoe. nlake.r and D. J. Roddy in 1988 and 1989, however, has shown that the. central uplift is flanked by steeply plunging folds. The Mt. Toondina Beds, in the. center of the strut.ture, consist of a sequence of steeply-dipping soft claystone, siltstone, sandstone, and minor coal, that are contorted into a series of tight folds and nappes. The type. section of the Mt. Toondina Beds, in fact, is overturned and was erroneously described in inverted strati graphic order by *Freytag*.

On the basis of geologic and geophysical data, Freytag concluded that the. Mt. Toondina structure was a piercement structure formed by a more or less cylindrical plug about 1.5 km wide of Middle or Late Tertiary age which penetrated Mesozoic units. Although alluding to an origin as a salt dome, the origin of the piercement was not specified. *Youles* [1976], in a brief note., suggested the Mt. Toondina structure was of impact origin. He based his interpretation chiefly upon similarities between the Mt. Toondina structure and the. Gosses Bluff impact structure in the Northern Territory [*Milton et al.*, 1972; *Barlow*, 1979]. *Wopfner* [1977] immediately challenged this interpretation and argued for an origin of the structure as a salt diapir, a conclusion also recently favored by *Jones* [1988].

Extensive seismic exploration of the Arckaringa basin has shown that salt is present in the late Precambrian (Adelaidean) stratigraphic section anti that numerous salt diapirs occur in the subsurface. However, the. diapirs arc all pre-Permian in age. Moreover, a seismic profile directly across the Mt. Toondina structure (see below) shows unequivocally that a salt diapir is not present at de pth at Mt. Toondina. The strong deformation at Mt. Toondina dies out with depth; strata are nearly flat lying at depths greater than ~800 m, the. base of the Permian Stuart Range Formation. The subsurface structure. is consist ent with that expected for an impact structure but not with a salt diapir.

GRAVITY SURVEY

Data Acquisition

An initial gravity survey of the Mt. Toondina structure was conducted in 1963. Those data were collected, reduced, and interpreted by J. Hall and the rc.suits reported in *Freytag* [1964, 1965]. That survey collected measurements along three northeast-oriented lines (N64°E) and three northwest-oricl]tcd lines (N26°W) centered at Mt. Toondina; measurements were m adc at an interval of 500 feet (152.4 m). Those data indicated a positive residual anomaly of ~1.5 mGal centered over Mt. Toondina. The anomaly was attributed by *Freytag* and also by *Jones* [1988] to a positive density contrast between Permian sediments exposed within the, central uplift and surrounding low-density Cretaceous shales.

To develop a more detailed understanding of the gravity field over the Mt. Toondina feature and determine its diameter and structure, additional gravity data were collected by us. Data were collected at intervals of 100 m along a two orthogonal lines across the structure (oriented N5°W and N85°E) and extending for a distance of ~4 km from the center, and along a line. running (N28°E) obliquely across the feature.. The N85°E and N28°E line.s coincide. with seismic reflection lines run by Dchi Petroleum Pty. Ltd. (see below). In addition to data acquired along the lines, numerous gravity measurements were collected on and around the central uplift. Figure 3a illustrates the location of the gravity stations used in this analyses and inc. udcs the ncw data as well as some of the 1963 data. The 1963 data were. provided to us by the South Australia Department Mines and Energy in the form of station locations and Bouguer gravity value.s (reduced using a density of 1.9 g cm⁻³). The two data sets were merged for this analysis using redundant site, measurements. All data were reduced using a density of 1.9 $g cm^{-3}$ as that density is representative of the bulk density of the Bulldog Shale, the upper most major strati graphic unit in the region (see below, Figure 6).

Gravity data were collected using a Worden gravity meter. All gravity values were tied to a base station at the central uplift. Base station

measurements were made every 2 to 3 hours to calibrate the mete.r drift. Data were reduced using the USGS Bouguer Gravity Reduction Program; no terrain corrections were made because of the lack of significant topography. No independent absolute gravity bases arc available. in the region, so a theoretical value for the appropriate latitude was assumed. Station locations (x, y, z coordinates) were determined using a Leitz SET 4 Electronic Distance Measuring unit. Location and elevation control was tied to the cairn at Mt. Toondina which had a reported elevation of 382 m [*Freytag*, 1965]. No additional bench marks occur within the survey area to provide. elevation control.

Data Analysis

Gravity in the area of South Australia around Mt. Toondina is marked by numerous positive and negative anomalies and significant gravity gradients. These variations arc attributed to the. density contrast between the. low-density Mesozoic and Permian sediments and the high]-density crystalline base.mcnl rocks and sediments of Cambrian-Devonian age [*Milton*, 1969; *Milton and Morony*, 1976]. The most pronounced of the density contrasts is between the high-density Devonian dolomites and the younger sediments. Seismic reflection data in the region indicate significant variations in the thickness of the sedimentary section and the presence of numerous fauns; the thickness of the sedimentary rocks overlying pre-Permian strata varies by more than a kilometer within the region.

Figure 3a illustrates the Bouguer gravity within 2..5 km of Mt. Toondina. Data extend over a 5 km x 5 km square centered on the central uplift. These data were gridded with a 50 x 50 grid and contoured with an interval of 0.5 mGal. At Mt. Toondina itself, Bouguer gravity is approximately -17.5 mGal. The regional gravity decreases to the. northwest with typical gradients of -1.5 mGal km $^{-1}$. Despite the relatively large gradients, the presence of a residual positive anomaly having an amplitude of 1 mGal associate. d with the central uplift is suggested by a deflection in the contours. The Bouguer gravity field is also displayed in an oblique 3-D view in figure 3b. The northwest regional gradient and the local high at Mt. Toondina arc clearly discernible in this representation.

Because of the regional gravity gradient, details of the gravity field associated specifically with the Mt. Toondina structure are difficult to resolve. In order to isolate these aspects, the regional trend of the gravity data was removed by subtracting a polynomial surface from the data and contouring the residuals. A third-order polynomial was chosen as the best approximation of the regional data such that the mean residual anomaly is approximately zero across the grid; the third-order polynomial accounts for ~97% of the total variation within the data. Residual gravity values were then gridded and contoured. A 50 x 50 grid with 100 m node. spacing extending 2.5 m from the central uplift was used to produce the contour map (Figure 4a). Also illustrated is an oblique 3D view of this residual field. Figures 4c and d illustrate the. polynomial surface that was subtracted from the data to produce the. residual field. The 3rd order polynomial is assumed to represent the regional gravity field. Seismic reflection data in the region indicate a thickening of the Permian and younger sediments 1 0 the northwe st [*Wopfner*, 1964] thus resulting in a decrease in the gravity to the nort hwest.

It can be seen in the residual gravity (Figures 4 a, b) that a well-defined positive. anomaly characterizes the central uplift and is surrounded by a series of closed contour lows. The lows completely surround the. central uplift, but arc of irregular depth. In part, some of the irregularity in the amplitude of the lows may be an artifact due to the, uneven distribution of stations; however, variation is observed even where station control is good. The variations probably reflect real differences in the thickness of the low-density near surface Cretaceous strata.

The dominant residual gravity feature is the positive anomaly centered over the central uplift. This high reaches a maximum amplitude of 1.0 mGal above the general regional level, and -1.5 mGal above the lowest areas of the annular low. It is -1. ?5 km in diameter at the O mGal contour. The central high is symmetric; the. margins of the anomaly arc marked by a steep gradient (~2.4 mGal km^{-1}) whereas in the center of the anomaly the gradients are much lower (~1 regal km^{-1}). The differences in gradient across the anomaly indicate that the source is shallow and sleep-sided. The surrounding low has a minimum gravity value of ~ -0.5 mGal in the. southeast and typically reaches levels of -0.3 mGal. Total relief across the gravity anomaly associated with the

structure is -1.5 mGal with the central uplift high extending significantly above the surrounding mean level. Outside the low, the residual gravity values return to approximately O mGal.

Most simple, bowl-shaped craters, are characterized by a negative gravity anomaly [*Innes*, 1961; *Pilkington and Grieve, 1992*]. Such negative anomalies can result from several processes. Examples of gravity lows due to infilling by low-density sediments include Wolf Creek Crater in Australia [*Fudali*, 1978] and Tenoumer in Mauritania [*Fudali and Cassidy, 1972*]. Examples of gravity lows resulting from the. impact breccia formed in the crater bottom include Meteor Crater in Arizona [*Regan and Hinze*, 197S] and Deep Bay in Canada [*Innes et al.*, 1964]. Shattering and fracturing of the original rocks and the, formation of impact breccia at the bottom of the c.rater results in a region of relatively low density which produces a negative residual gravity anomaly centered over the crater.

The shape of the gravity anomaly at Mt. Toondina is consistent with that of a complex impact crater, i.e.., one which has a central uplift. Complex craters display a more complicated gravity signature due. the presence of a central uplift. Typically the central uplift is composed of relative.ly high density mate.rial brought up from depth (particularly in craters having diameters greater than 30 km). This high density material, in contrast to the surrounding lower density material, results in a positive gravity anomaly. An example of similar size to Mt. Toondina is the Connolly Basin structure in Western Australia (*Shoemaker et al.*, 1989; *Shoemaker and Shoemaker*, 1989). Connolly Basin is a 9-km-diameter impact structure characterized by a 2. mGal gravity high associated with the central uplift due. to relatively high-density rocks brought up. Although vastly larger, the. Manicouagan impact in Quebec (65 km diameter) shows a pattern similar to that exhibited at Mt. Toondina [Sweeney, 1978]. Manicouagan has a central gravity high due to relative high-density rocks surrounded by an annular low; total gravity relic.f is about 8 mGal. However, this pattern of a central gravity high is not always the case; at the Steinheim basin the central uplift is characterized by a negative gravity anomaly [*Pilkington and Grieve, 1992*].

SEISMIC REFLECTION DATA

Unraveling the structure at Mt. Toondina has been greatly facilitated by two seismic reflection lines which cross the feature. One of the lines (85 YQZ) trends nearly cast-west (Figure 5) and passes directly across the central uplift: the second line (85 XQF, not shown) trends northeast and passe.s obliquely across the structure. Record sections for these lines were kindly provided by the South Australian Department Mines and Energy.

The cast-west line record section (Figure 5) shows a series of prominent reflectors at depths of 0.2, 0.6, 0.8-0.9, and >1 sec. These reflectors can be traced across much of the Arckaringa Basin and can be tied to specific strati graphic. units at the Cootanoorina well [Wopfner, 1970; Hibburt, 1984], 7 km southwest of Mt. Toondina. Reflectors in the Cadna-owie Formation, the Algebuckina Sandstone, the Mt. Toondina Beds, and the underlying Stuart Range Formation of Permian age can be traced in the seismic record section from the Cootanoorina well to Mt. Toondina. The "V" shaped gore extending between stations 540 to 585 is a gap in the data where. steeply dipping beds of the central uplift were avoided.

Outside the Mt. Toondina structure, at stations <460 and >660, the reflectors at depths less than 1.() sec are continuous and essentially flat lying. Near the center of Mt. Toond ina (station 560) the reflectors a t shallow levels, corresponding to the Bulldog Shale, Cadna-owie Formation, Algebuckina Sandstone, and Mt. Toondina Beds, all steepen and become shallower toward the center. These reflectors can all be extrapolated to the surface where. they are observed to correlate with the same units in outcrop with which they are. correlated from well data. Surrounding this uplift (near stations 510 and 600) is a zone where the. reflectors are depressed below their regional level. Several reflectors farther away from the center, at stations 490 and 640, are offset by faults. Displacement along the faults is down toward the center of the structure. At depths greater than -0.6 sec the reflectors assigned to the Adelaidean strati graphic section are essentially continuous beneath the structure. q'here is a hint of slight disruption of strata at this depth, although the disruption may be an artifact re.suiting from velocity effects within the overlying disturbed zone. The. northeast-trending seismic reflection line

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which trends obliquely across the edge of the structure shows a shallow depression where it crossed within the crater ring structural depression. This same depression is observed in the east west profile at stations 510 and 600. The units in the northeast trending line observed to be depressed -0.04 - 0.06 sec relative to their surrounding level.

The seismic reflection data indicate that the strata above the base of the Stuart Range Formation have been pushed Up into the, central uplift at Mt. Toondina. Surrounding this uplift, the strata have dropped downward and inward, in part, along a series of normal faults. This downward and inward motion resulted in the formation of a ring structural depression surrounding the central uplift. The reflection data also indicate that all of the deformation occurs above the base of the Stuart Range Formation; strata at deeper levels are. essentially undisturbed, as indicated by the continuity of the reflectors. Thus, the strong deformation affects only units of Permian and younger age.

GRAVITY MODELING

Density Determinations

in an effort to constrain gravity models of the Mt. Toondina structure, hand specimens of the local geologic units were. collected for density analysis. Samples of the Mt. Toondina Beds were collected from the section described by *Freytag* [1965] and elsewhere in the central uplift. Cadna-owie Formation samples were obtained from a spoil pile on the flank of the central uplift. The Algebuckina Sandstone samples were collected at outcrop around the central uplift and samples of the Bulldog Shale were collected south of and along the. east flank of the uplift. Most samples are somewhat weathered.

Figure 6 illustrates the density cjc.termination for each of the various rock types sampled for each formation. Several density dc.terminations were made for each rock type from both multiple, samples and subsamples from single hand specimens. The error bars shown in Figure 6 indicate the variation in the calculated density; the predominate source of measurement uncertainty is the volume of the sample. Densities were measured on dry

samples; wet densities would be significantly higher, particularly for sandstones.

Average densities for various rock types exposed at Mt. Toondina range from 1.6 to 2.9 g cm^{-3}; most samples are in the range of 1.8 - 2.0 g cm^{-3}. The sandstorms of the Cadna-owie Formation and the Algebuckina Sandstone have the highest densities (1.9 - 2.9 g cm^{-3}), but these are relative thin units. (Combined thickness of both formations at Mt. Toondina is about 75 m.) Densities for rock types within the Mt. Toondina Formation range from 1.6 g c m^{-3} for carbonaceous claystones to 2.0 g cm^{-3} for clayey sandstones. As the Mt. Toondina Beds are characterized by siltstone with minor sandstone, the formation density is probably in the range. of 1.9 - 2.0 g cm^{-3}. As these density determinations were made on dry sample.s, they represent minimum values. Water saturation, as would occur in situ, would increase the densities as much *as 10-20%* above that for dry samples. in addition, seismic refraction data for the region [*Moorcroft*, 1964] indicates velocities of 2.59 km sec^{-1} for shallow units and 5.2 to 5.7 km see-' for material at depths greater than 600 m. These velocities corre.spend to densities of 2.2 to 2.7 g cm^{-3}. Therefore, on the basis of the. measured dry densities, the in situ geologic conditions (water saturation), and the velocity data, the mean densities of these formations are considered to be greater than the measured values for dry surface samples.

Our density data are consistent with those reported by *Milton and Morony* [1976] who cite average densities for the Permian and Mesozoic sediments of the Arckaringa Basin of -2.07 g cm^{-3} and 2.65 g cm^{-3} for crystalline. basement rocks. Not all sediments within the basin are, however, of such low density. Dolomites from the. Wintinna and Boorthanna Troughs have densities of 2.64 to 2.85 g cm^{-3}, Ordovician (?) quartzites from tile Boorthanna Trough have densities of 2.69 g tin^{-3}, and some Permian and Mesozoic sedimentary rock have densities of 2.25 g cm^{-3}.

Modeling

In order to better understand the. origin of the gravity anomalies and tile.ir implications for crustal structure, we have modeled the residual gravity anomaly using a 2 1/2 D gravity modeling program. Constraints on the gravity

model arc provided by the exposed geology; two seismic reflection profiles which cross the structure; stratigraphic control from the outcrop and from seismic correlation with the stratigraphic control at the Cootanoorina well; and densities determined from samples collected of Mt. Toondina. The local Permian and Mesozoic stratigraphy consists of about 260 m of Stuart Range Formation, 330 m of Mt. Toondina Beds, 10 - 40 m of Algebuckina Sandstone, 30 m of Cadna-owie Formation, and 100 m of Bulldog Shale [*Wopfner*, 1970; *Allchurch et al.*, 1973; *Hibburt*, 1984]. The Permian strata rest unconformably on beds of possible Devonian age which arc, in turn, underlain by a thick sequence of late Precambrian a n d Cambrian strata (Adelaidean).

The gravity model of the Mt. Toondina feature includes three. layers (Figure 7): (1) the lowest layer in the. model represents the Mt. Toondina Beds and has a thickness of 330 m and a density of 2.1 g cm^{-3}; (2) a middle layer is 75 m thick, has a density of 2.10 g cm^{-3} and corresponds to the older Mesozoic units (Algebuckina Sandstone a n d Cadna-owie Formation); a n d (3) the uppermost layer is 100 m thick and has a density of 1.91 g cm^{-3} and corresponds to the Bulldog Shale.. Observed residual and calculated gravity arc fairly well matched in a model in which the Mesozoic units and Mt. Toondina Beds arc brought to the surface in the central uplift and the upper two units arc depressed by -90 m in an annular zone slightly more than 1 km wide. surrounding the central uplift. The densities used in the model arc greater than (hose estimated from hand sample., but given the other constraints discussed above, these model densities arc probably consistent with the in situ densities of these materials.

The result of the high density units being brought to the surface in the central uplift, in relation to the lower density Bulldog Shale surrounding the central uplift, is a central gravity high surrounded by an annular gravity low. The gravity model further indicates that the Mt. Toondina impact structure has a diameter of about 4 km, that the structural relief within the central uplift exceeds 200 m, and that the, region around the central uplift has been depressed by ~90 m relative to its normal stratigraphic depth.

The gravity model is not unique, in that many combinations of densities and model body dimensions can reproduce the observed anomalies. However,

the model is consistent with the observed geology at the surface, the seismic reflection data, sample densities, and structure expected for an impact crater. Although the annular low is modeled as being the. result of down warping of the Bulldog Shale., as suggested by the de.pressed reflectors in the seismic profile, part of the mass deficit, particularly at deeper levels, might result from the presence of impact breccia or simple fracturing of the. rocks to reduce the density.

DISCUSSION

The suggestion of previous investigators [*Freytag*, 1964, 1965; *Wopfner*, *1 9/7; Jones*, *1988]* that Mt. Toondina is a salt dome was based chiefly on the diapir-like relationship of the rocks of the central uplift to the beds of the surrounding region and discovery of salt domes in other parts of the Arckaringa Basin. However, a salt dome model is not consistent with the observed data: (1) salt does not occur in the area in Permian and younger units; (2) although salt dots occur in the region and salt domes are present (e.g., 80 km northwest of Mt. Toondina), the salt occurs in the late I'rote.rozc)ic Adelaidean rocks [*Sani*, 1986]; and (3) the structural deformation at Mt. Toondina is limited to Permian and younger units. Deformation of the exposed beds of the central uplift at Mt. Toondina involves circumferential shortening and uplift, as in a diapir. It is the elastic. rocks of Permian to Cretaceous age that arc so deformed, not salt. Beds that overlie salt diapirs tend to exhibit extensional rather than compressional deformation. The central uplifts of impact structures do indeed resemble diapirs. However, emplacement of these uplifts is driven not by bouancy, but by prompt collapse of the transient cavity walls and flow of the displaced material toward the center of the. crater. As at Mt. Toondina, these uplifts arc commonly marked by posit ve gravity anomalies.

The Mt. Toondina structure can be most closely compared with the Steinheim Basin, Germany, of Middle Miocene age [*Reiff*, *1977]* and the Flynn Creek, Tennessee, partly buried crater of Late Devonian age [*Roddy*, 1977]. Both impact structures arc formed in nearly flat-lying sedimentary rocks and arc about 3.5 km in diameter, similar to the size of the Mt. Toondina structure. Both arc partly filled craters with pronounced dial)ir-like. central uplifts that

underlie the central topographic peak. Surrounding the central peaks are relatively flat floors which are underlain by fairly shallow structural depressions.

In Australia, the closest known structural analog to Mt. Toondina is the Connolly Basin of Cretaceous age [Shoemaker *and Shoemaker, 19891*. The Connolly Basin is an exhumed crate.r about 9 km in diameter with a relatively small central uplift. Connolly is also underlain by Precambrian salt deposits and is close to known salt diapirs [*Wells*, 1980]. A seismic profile. across the center of the Connolly structure reveals that the salt is essentially undisturbed at depth beneath the feature. The central uplift is surrounded by a structural moat bounded by normal faults. A positive residual gravity anomaly is localized over the central uplift; it is surrounded by a sequence of subdued gravity highs and lows [*Shoemaker et* al., 1989].

Seismic reflection profiles revealing broad structural features somewhat similar to those at Mt. Toondina have been obtained for many impact structures around the world including the Mjolnir structure in the Barents Sea [*Gudlaugsson,* 1993]; the Red Wing Creek structure in North Dakota [*Brenan*,]97S]; the Haughton impact structure in arctic Canada [*Hajnal et al.*, 1988; *Scott and Hajnal*, 1988]; the Siljan impact structure in Sweden [*Juhlin and Pedersen*, 1987]; and the Tookoonooka structure in the Eromanga Basin of Australia [*Gorter et al.*, 1988]. Structural patterns somewhat similar to those observed in the seismic reflection profiles for Mt. Toondina are also observed in the larger Talundilly structure of the Eromanga Basin in Queensland [*Longley*, 1988] and at Connolly Basin. The Talundilly feature. has been suggested to be a buried impact crater. It's saucer shaped depression is -95 km in diameter and up to 1 km deep buried beneath Cretaceous beds. In the outer part of the structure reflectors are dropped down along a series of inward-dipping normal faults. At the center of the structure, the. reflectors are bent up into a central uplift. The reflection data indicate, that within the disturbed zone, a raised rim, depressed structural moat, and central uplift can be recognized. The feature at Talundilly is also characterized by a positive gravity anomaly centered over the central uplift.

The structural relief of the central uplift at Mt. Toondina is consistent with data for other collapsed impact craters. *Grieve et al.* [1981] presents the relation $SU = 0.06D^{1.1}$ where SU is the average structural uplift and D is the crater diameter in km. This relation would indicate a structural uplift of about 2?80 m for a diameter of four km. When account is taken of upward displacement within the Mt. Toondina Beds that is not recognizable in the gravity model, the observed relief at Mt. Toondina is entirely consistent with average expectations.

SUMMARY

The gravity data combined with the seismic reflection data and surface structural geologic mapping for the Mt. 'Toondina structure in South Australia, reveal that the central uplift is surrounded by a ring structural depression. Detailed geologic mapping indicates that the Permian, Jurassic (?), and lower Cretaceous beds of the central uplift have all been deformed in convergent centripetal flow. Further, the seismic reflection data show that deformation dies out with depth. Below -800 m, the reflectors pass beneath the structure undisturbed indicating little or no deformation below this depth.

The Mt. Toondina impact structure is defined by a simple residual gravity anomaly. Relative to the adjacent terrain, the central uplift is marked by a positive anomaly of + 1 mGal, 1.2 km in diameter, surrounded by an annular gravity low (-0.5 mGal) having a width of -1 km. The overall diameter of the feature is -4 km. Gravity modeling suggests that relatively high density units (Algebuckina Sandstone, Cadna-owie Formation, and Mt. Toondina Beds) have been raised up into the central uplift in excess of ?00 m and that the surrounding Bulldog Shale fills a ring structural depression within the crater interior that is -90 m deep

ACKNOWLEDGMENTS

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Fig. 1. Map showing location of Mt. Toondina impact strut.tum in South Australia.

Fig. 2. Oblique aerial view to the west of the Mt. Toondina structure showing the central uplift and surrounded by gently sloping surficial deposits. The dark ring is formed by trees and brush concentrated along the Algebuckina Sandstone aquifer; a wavy line of trees following the Algebuckina outcrop reflects steeply plunging folds. The bright material in the center is salt crusted outcrop of the Mt. Toondina beds. The bright line extending across the feature from top to bottom is a road along which the seismic reflection line (85 YQZ) was acquired; other roads are also evident.

Fig. 3a. Bouguer gravity map of the region; contour interval is 0.5 mGal. Station locations are indicated by crosses. Data include points within an 8 km x 8 km square centered on the central uplift. Fig. 3b. Oblique view mesh map of the Bouguer gravity field viewed from the southeast. X and Y axes dc.note distances in meters relative to the center; vertical axis is residual gravity in mGal.

Fig. 4a. Residual Bouguer gravity field. 3rd order polynomial has been removed to produce the residual. Contour interval is 0.1mGal. Crosses indicate station locations. Fig. 4b. Oblique mesh map view of the residual gravity field viewed from the southeast. The central high and surrounding low are easily seen from this perspective. X and Y axes denote distances in meters relative. to the center; vertical axis is residual gravity in mGal. Fig. 4c. 3rd order polynomial field removed from Bouguer gravity. Fig. 4d. 3rd order polynomial field shown in oblique view from the southeast.

Fig. 5. East-west seismic reflection profile (85 YQZ) across the center of the. structure.. Residual Bouguer gravity values are plotted above. Faults are shown as solid lines.

Fig. 6. Density determinations for samples collected at Mt. Toondina. Measurements have been averaged by rock type. Variations in the calculated densities among samples arc indicated by error bars,

Fig. 7, Two and a half dimensional gravity model showing a proposed structure of the Mt. Toondina impact. Horizontally stripped unit is the Bulldog Shale ($p = 1.9$ g cm^{-3}); stippled unit represents the Algebuckina Sandstone and the. Cadna-owic Formation ($p = 2.1$ g cm^{-3}); the underlying white unit is the Mt. Toondina Beds ($p = 2.12$ g cm^{-3}). Circles in the upper panel indicate residual gravity, the solid line is calculated gravity. Vertical exaggeration is 10:1 in the model cross section.
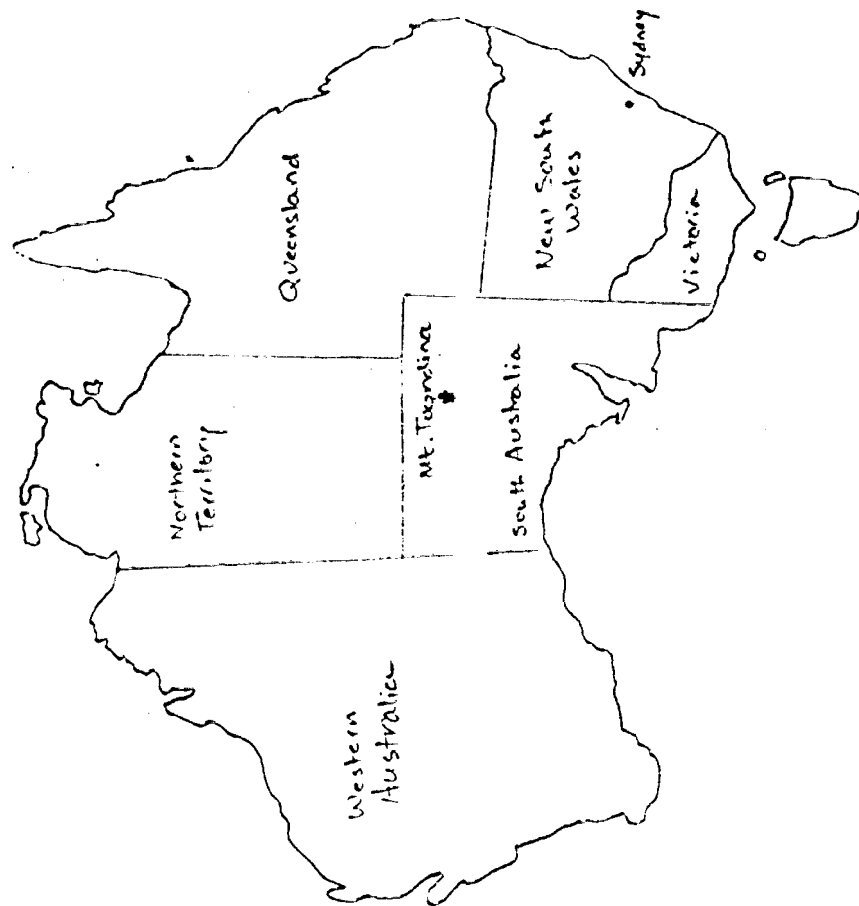
FIGURE 1.

FIGURE 2.

MT. TOONDINA - BOUGUER GRAVITY
50 X 50 GRID WITHIN 4 KM OF CENTER

FIGURE 3A.

23

FIGURE 3B.

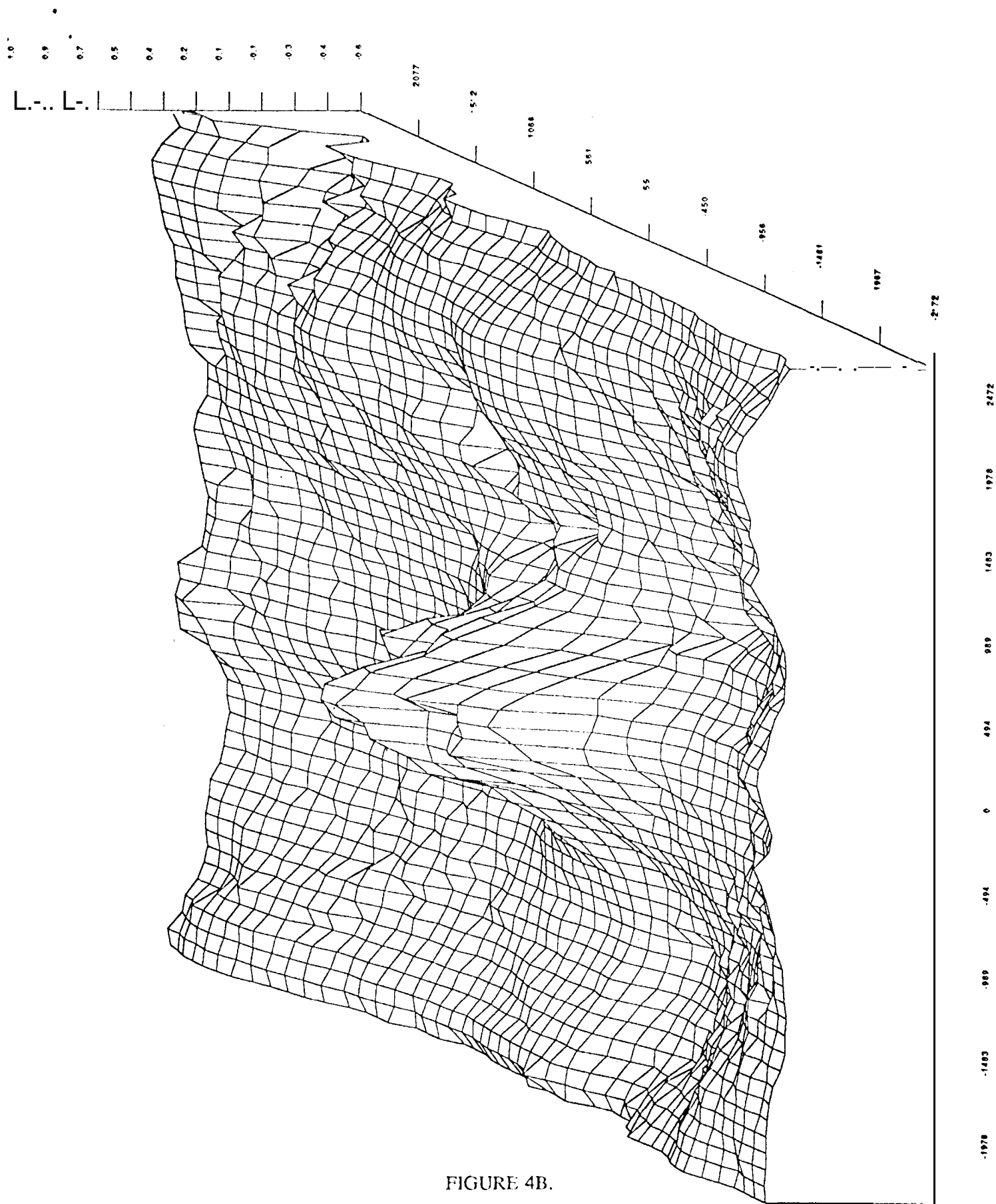MT TOONDINA RESIDUAL BOUGUER GRAVITY

3RD ORDER RESIDUAL GRAVITY

FIGURE 4A.

FIGURE 4B.

26

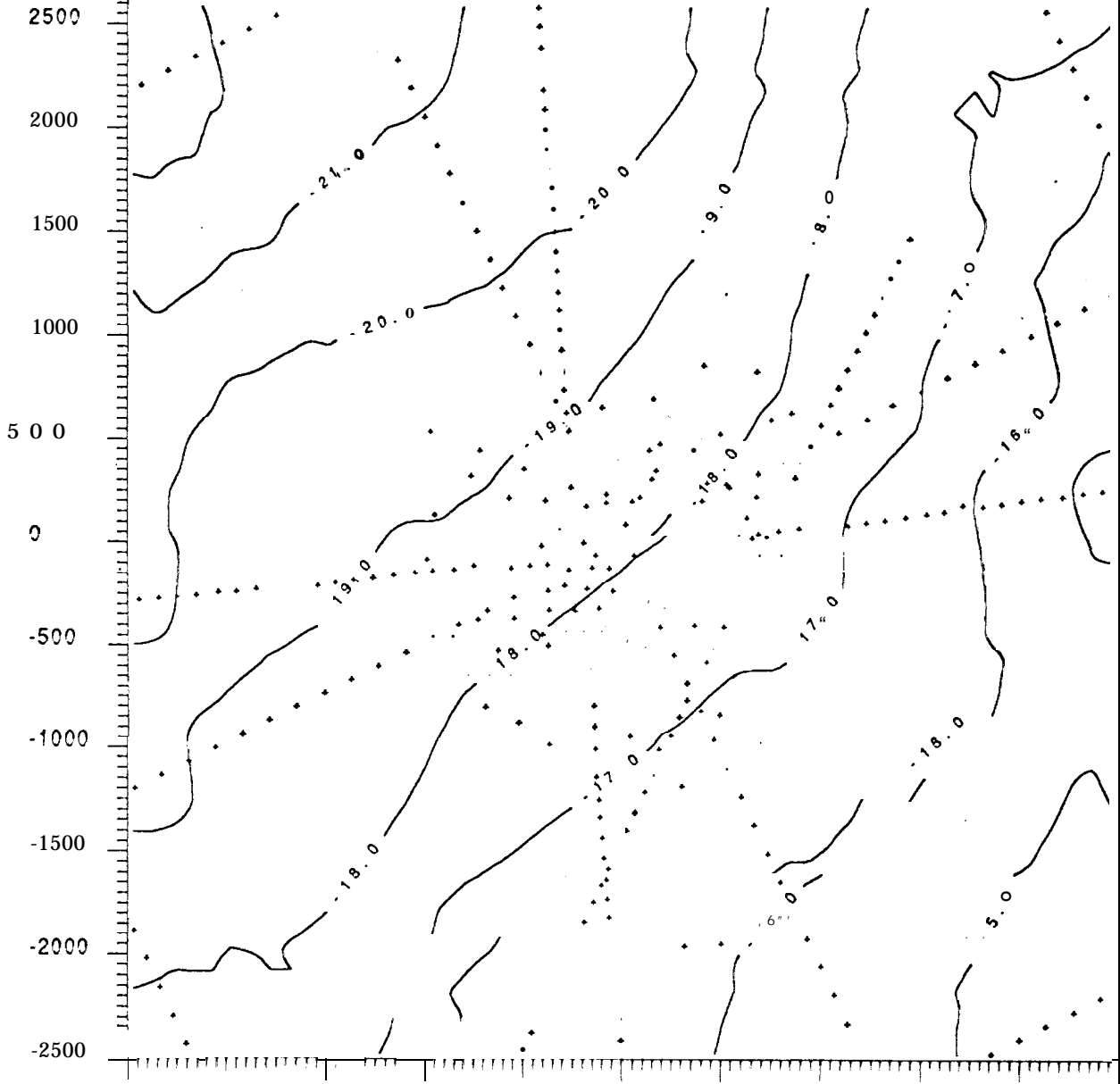MT TOONDINA RESIDUAL BOUGUER GRAVITY
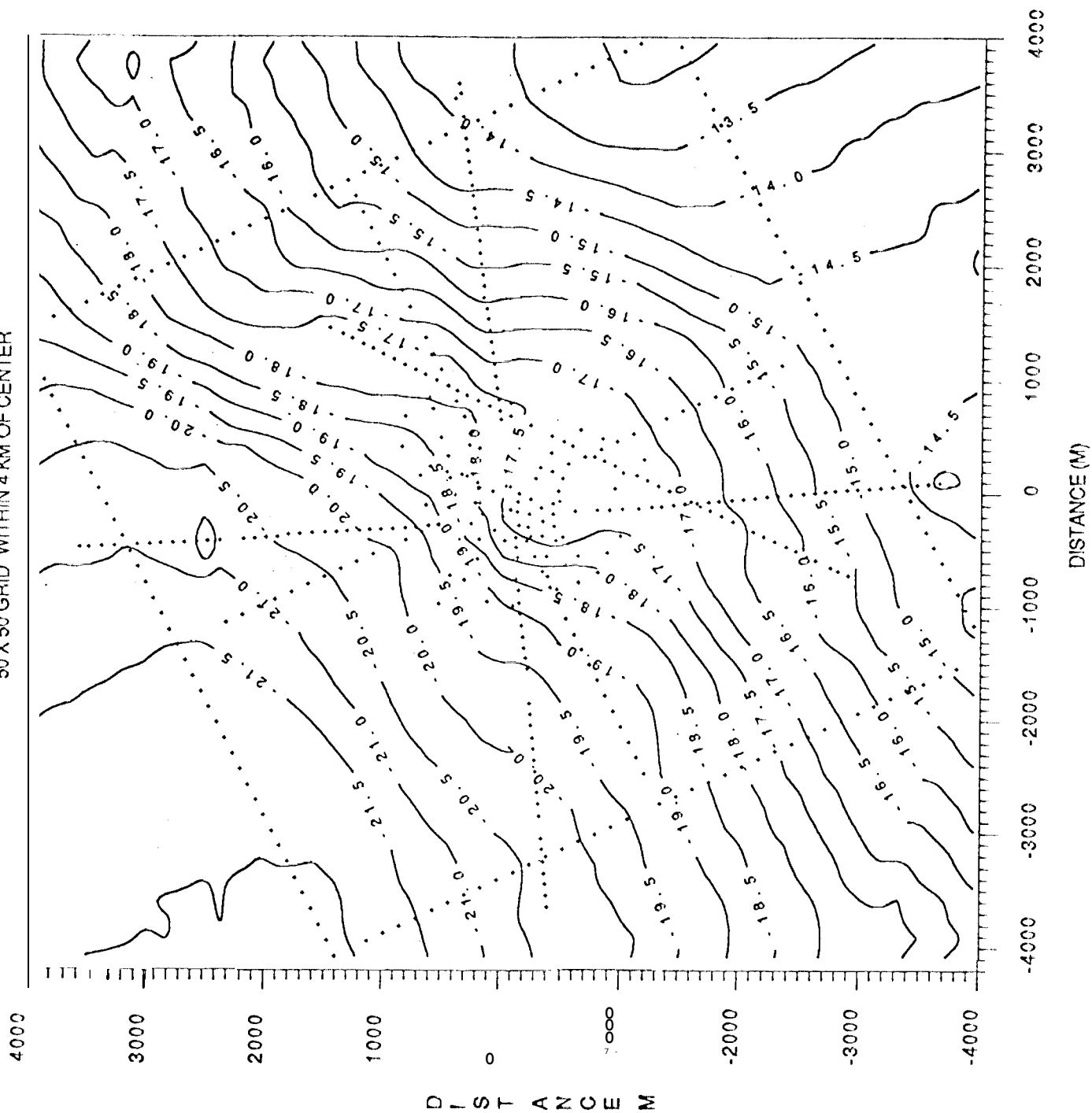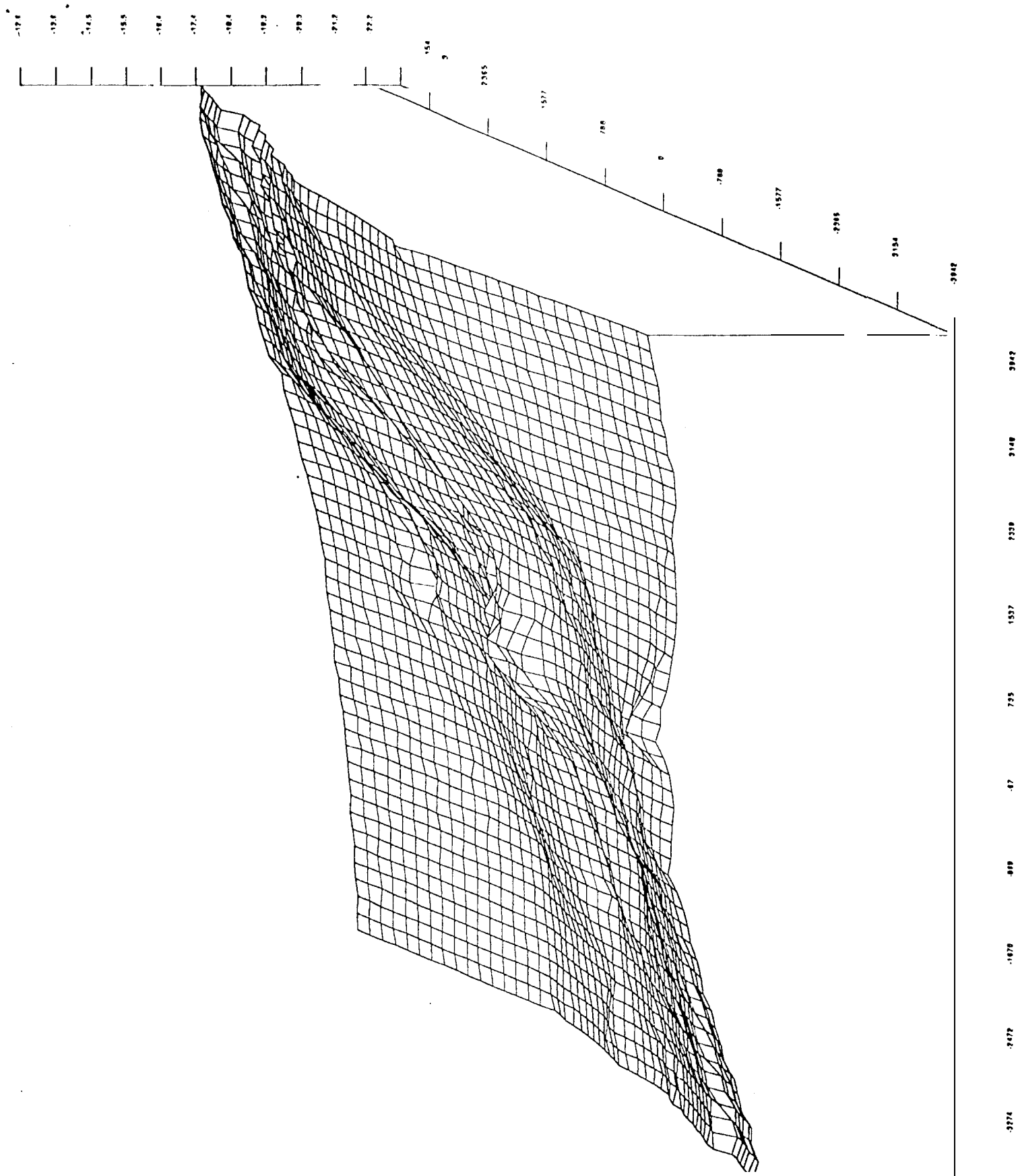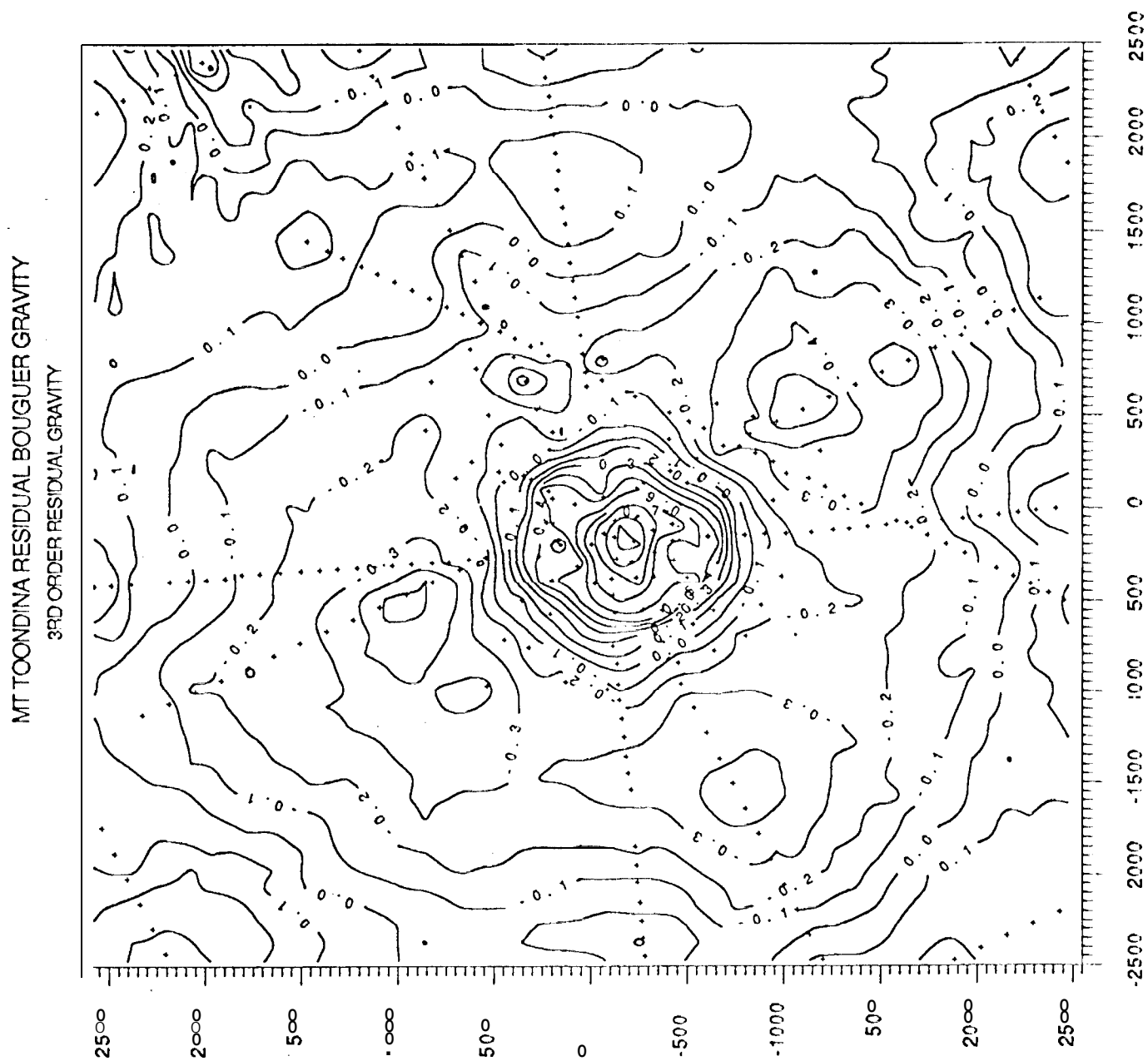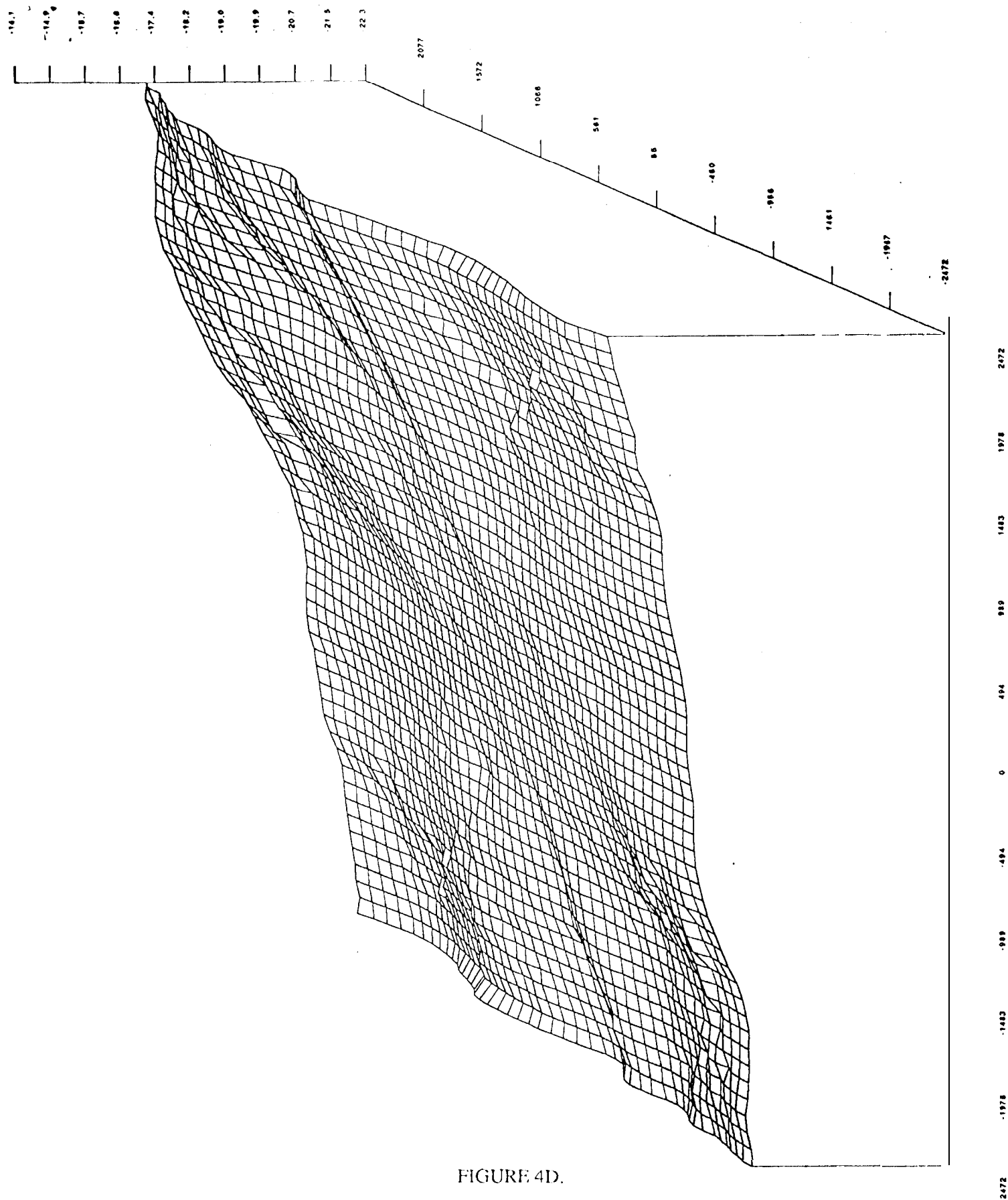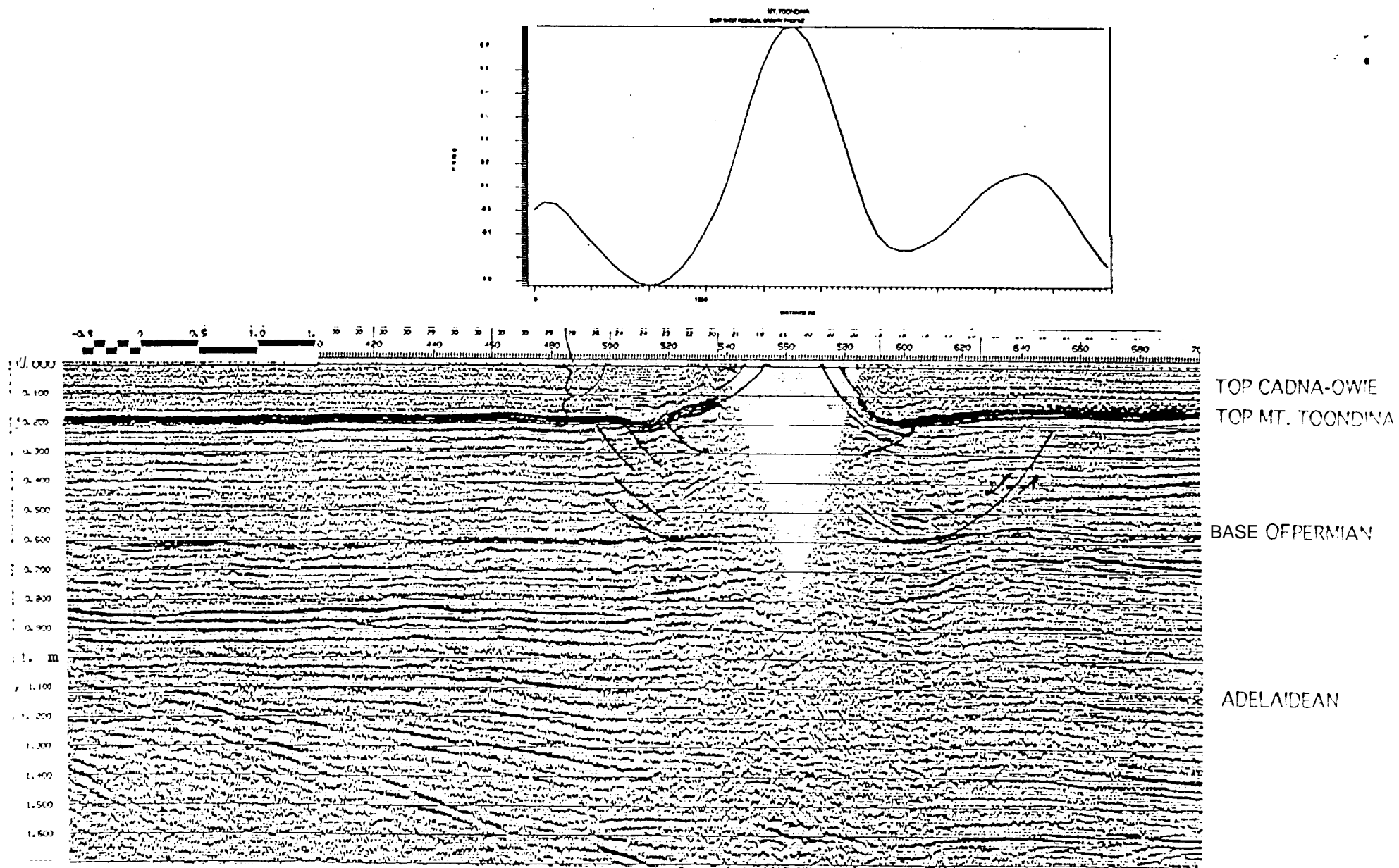
3RD ORDER TREND SURFACE

FIGURE 4C.

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FIGURE 4D.

FIGURE 5.

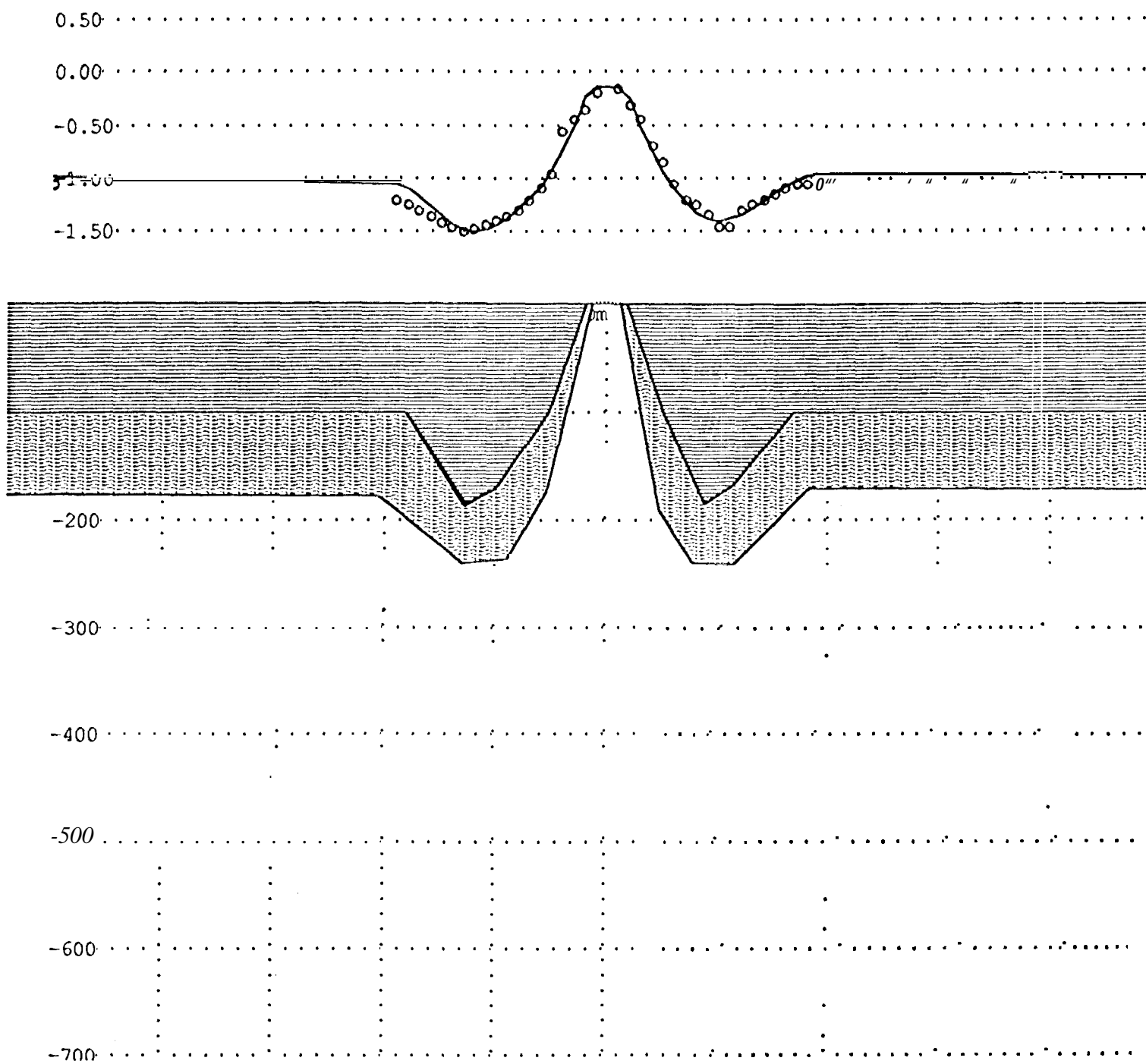MT. TOONDINA UNIT DENSITY DETERMINATIONS

FIGURE 6.

FIGURE 7.